# THE WORLD OF CHEMISTRY

Program #13

THE DRIVING FORCES

Producer John Boslough

Air Script: October 31, 1988

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Annenberg/CPB Project Logo and Music

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MONTAGE: Rocket launch, grapes, match lighting, construction, pouring wine, bread rising, explosion

NARRATOR (NAT SOUND under): We live in a world of molecules interacting with other molecules in chemical reactions. What makes the reactions occur? Why are some fast, and some slow? The rate of a reaction turns out to be critical, whether you're involved in construction, or wine making, or simply preparing food. To understand these dynamics, we must probe the driving forces.

SUPER: THE DRIVING FORCES

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in apple orchard

ROALD HOFFMANN (SYNC):
Chemistry is not just bottles on a shelf. That would be pretty dull. It's about chemical reactions, about compounds changing to make other compounds, about molecules bouncing around. It's a wonderful world of transformations. Take this apple tree. It grew from a seed, but, on the way, it used water from the soil, minerals and fertilizers from the soil. Also it took in carbon dioxide from the air, and the sunlight provided it with the energy to do what? To run a chemical factory making a whole host of marvelous molecules, the chlorophyll in the leaves, the pigments in the skin of the apple, the sugars within, and it's still not static. Those leaves are going to change color. They are going to turn yellow. That's another chemical reaction. This whole tree will die someday. That's another set of chemical transformations.

MONTAGE: Volcano exploding, lava flowing, lake, city street scenes, river rafting, flower blooming, wood burning in fireplace, automobile driving, testing chemical plant water, drop of water in glass

NARRATOR (MUSIC and NAT SOUND under):
Every change has a natural direction in which it occurs, whether in the wilderness, or in the bustling world we've created. Rivers flow to the sea, never the reverse. In a complex series of chemical reactions, a flower blooms, then shrivels and dies, never the reverse. Wood burns, producing carbon dioxide and water. An automobile burns gasoline to carbon dioxide and water, and also produces heat and power for motion. In a vast chemical plant, an array of chemical reactions takes place. Here, for instance, ethylene reacts with water to make ethyl alcohol. Why do all these changes go the way they go? What determines the natural direction of a chemical reaction? When wood burns, the energy of the system decreases and heat is released to the surroundings. This tendency to reach a lower energy is one of the forces that drives all chemical reactions. In the natural direction of most chemical reactions, the energy of the system decreases. Dr. Donald Showalter.

DS in lab

DON SHOWALTER (SYNC):
In this reaction, the reacting materials are potassium permanganate, this dark purple solid on this screen, and glycerine, this thick liquid. Now let's see what happens when we mix them. I'll put the glycerine onto the permanganate. Oop! There's some smoke coming out. Oh, look at the flame. Well, that reaction certainly releases energy, doesn't it? Now, what happened is that glycerine is a combustible organic liquid, and potassium permanganate is a concentrated source of oxygen. So when the two come in contact, they ignite spontaneously. So this kind of chemical reaction releases energy. The key word is "release." This is the type of reaction we call exothermic.

GRAPHIC: Energy diagram for exothermic reaction

NARRATOR:
In an exothermic reaction, the reactants have relatively high energy. The energy is depicted here in kilojoules. The products of the reaction have a lower energy. As the reaction proceeds downhill from high energy to low energy, reactants are converted to products and energy is released by the system, in this case, 300 kilojoules per mole reactant.

Shots of paper burning,
car driving down highway,
bread rising

NARRATOR (NAT SOUND under):
As we have seen, most chemical reactions tend to release energy, usually in the form of heat. An automobile is designed to release energy in the form of motion down the highway and the heat from the engine. What about reactions in which heat is absorbed?

DS in lab

DON SHOWALTER (SYNC):
This time I want to do a reaction that takes in energy. Now, how're we gonna see that? Let's do the reaction and find out. I'm going to mix barium hydroxide, a white solid, with another white solid, ammonium thiocyanate, and before I mix them, I'm gonna put a little water onto this board, and I'll move that water over here, put the beaker onto the board right on top of that water, then I'll put the solids in there, and we'll see what happens. There's the barium hydroxide, and here's the ammonium thiocyanate. I'm gonna mix it. Oh, it's getting moist in there. It's getting liquid. And that's understandable, because one of the products is water. You can also smell a little ammonia coming off of there. That's another product. Oh, the beaker's getting cold down at the bottom now. (cont.)

DON SHOWALTER cont:
I'll keep stirring so that the reaction proceeds, and we'll see if we can tell whether or not energy is taken in. Oop! Look at this! The beaker is frozen to the board. This is an example of an endothermic chemical reaction, one that takes in energy. In this case, the energy is taken in from the surroundings. That's why the beaker got so cold that it was able to freeze that little bit of water that I put on that board. So the beaker is frozen, very tightly, to that board. Look at that!

GRAPHIC: Energy diagram for endothermic reaction

NARRATOR:
In an endothermic reaction, the reactants have a relatively low energy. The products have a higher energy. As the reaction proceeds along the uphill slope from low energy to high energy, reactants are converted into products. In this process energy is absorbed, in this example, 400 kilojoules per mold reactant.

Shots of bees in flowers,
bread on assembly line,
blast sites

NARRATOR (MUSIC and NAT SOUND under):
Many important chemical reactions take in energy. Plants and animals will not grow without an infusion of energy. Reactions involved in cooking food also require that energy be absorbed. (SFX: Blast) But an energy change is not the whole story. There's a second driving force, a tendency towards increased disorder. The scientific name for this disorder is entropy.

DS in lab

DON SHOWALTER (SYNC):
Entropy is a fascinating subject. Let's see how it works. I've got a couple things to do that will show how entropy works as a driving force. Let's do this one first. This beaker has pure water. I'm gonna add a few drops of dye to that. Now, I already know that the dye and the water will not react chemically. Look at that! The dye and the water are mixing slowly in there, and they're doing that by them -- by itself. I'm not helping it out at all. Well, let me speed it up, though, a little bit. Now, any mixture is in a greater state of disorder than it is in the original materials. Now do you think we can get them back into their original containers? (cont.)

DON SHOWALTER cont:
(MUSIC/SFX up and out) But that's just a TV trick. We know that's not the way it happens in the real world. But what does this show us? That going from a state of disorder to a state of greater order is not the natural direction for almost any process. Let's try something else. Here I have some lettuce, and some tomatos, and some peppers. Get all those tomatos in there. Mushrooms, and cucumbers. You know what I'm gonna do. I'm gonna make a salad. I'm gonna toss that salad up here. Oh, it looks pretty good, huh? Stay in here. Looks pretty good to eat. If I kept tossing this now, will the salad go back to its original unmixed state? Well, you know the answer just as well as I do. Like the dye in the water, the salad shows us that the natural direction of change is toward greater and greater disorder, more entropy, increased entropy. Now, this is true for virtually any chemical reaction.

Shots of chemical reactions, lab shots, liquids, gases, chemists working in lab

NARRATOR (MUSIC and NAT SOUND under):
In what ways can entropy increase in a chemical reaction? There is more disorder, or greater entropy, if more molecules are formed. (cont.)

NARRATOR cont:
There is greater entropy if a liquid is formed from solids, or if a gas is formed from liquids or solids. And entropy rises if a mixture is formed, or if the volume of a gas is increased. Look again at the reaction that made the beaker freeze to the board. Why did this reaction occur? Energy was absorbed and the entropy increased. A liquid mixture, with more disorder, was formed in the beaker from two crystalline solids. The increase in entropy was large enough to overcome the absorption of heat. This must be true for all endothermic reactions. In industry, reactions have to work. Both energy and entropy effects determine that. If a reaction does work, if new molecules can be created, then the industrial design is given to the engineers and they focus on energy and materials.

Exterior and interior shots of Union Carbide plant in West Virginia

NARRATOR (MUSIC and NAT SOUND under):
West Virginia. Union Carbide. Chemicals for 500 different products: detergents, adhesives, plastic wraps and car seats, paints and waxes. Probe the panoply of pipes and towers and you find more than a flow of materials. (cont.)

NARRATOR cont:
There's a flow of energy. Energy. Amidst scores of chemical reactions, the engineers must conserve it. Usually a reaction is exothermic, giving off heat. Plant designers want to reuse this heat to drive other reactions, to minimize waste of energy in the whole plant. So through the red pipes in this scale model, they'll transport steam, and out in the plant, steam is piped from point to point, reaction to reaction. Materials. The basic raw materials coming into the plant are coal or petroleum, both high in energy. First, ethane gas is produced, and then, by selective addition of oxygen to ethane, we get a variety of industrial chemicals.

SUPER (over plant shot):
Ethane, Ethyl Alcohol, Ethylene Glycol, Acetic Acid, Carbon Dioxide

NARRATOR (NAT SOUND under):
The plant is constructed so that each product in the chain of reactions has a successively lower level of energy. Ethane is at the top of the energy ladder. From this, ethyl alcohol is produced. Below that is ethylene glycol, used in antifreeze and adhesives. A further step down the ladder produces acetic acid, for polymers like vinyls and rayon. And at the bottom of the energy ladder are carbon dioxide and water.

RH at construction site

ROALD HOFFMANN (SYNC):
So whether a reaction will go or not depends on the balance of energy and entropy of the reactant and the product. And we can trade off one of these against the other. For instance, human beings like to have ordered things around them. We like to build. Can we construct such a local ordering, a local defeat of entropy in our environment? Yes, we can, if we put in energy. That is what is going on in this construction site in back of me. Energy and entropy tell us whether a reaction will go, but not actually how quickly it does go. For instance, concrete is being set in that building. It's important that it's set in hours and not in seconds, and not in days. Let's look at the rates of chemical reaction and how we can influence them.

MONTAGE: Construction, roads, dam, buildings, concrete trucks

NARRATOR (MUSIC and NAT SOUND under):
Roads, dams, bridges, churches, houses, and offices. There's chemistry in all that concrete. Trucked in slowly turning drums, the mixture of water and cement and gravel cannot set into concrete until it's spread on site. (cont.)

NARRATOR cont:
Boxed in place, it will be left to react slowly, water and cement reacting to produce microscopic bridges of calcium silicate with the gravel. If wooden forms are not left in place long enough, if not enough time is allowed for reaction completion, the consequences can be disastrous.

Still photographs of collapsed apartment building

NARRATOR (MUSIC and Siren SFX under):
In Virginia, in 1973, the rubble remains of a partially collapsed apartment complex. Fourteen died. Too much haste for the slow reaction rate which makes hard concrete. The rate of any chemical reaction depends on several factors. Don Showalter.

DS in lab

DON SHOWALTER (SYNC):
Let's take a look at one of the most common reactions of all, simple burning. Here I have a piece of wood. We all know that wood, if dry, will burn readily in air. Remember, air is about 21 percent oxygen. It's not burning. Oop. We've got to warm it up, don't we, to get it going. Let me warm it up with this match. Oh I'll warm it up, the oxygen of the air reacts with the wood. There it starts going. (cont.)

DON SHOWALTER cont:
Now, that's burning pretty well, but not really well. I wonder if it would burn any better in this 100 percent oxygen. Well, let's see. Oh, look at that. The rate of reaction has drastically increased. Now, what does this tell us? Well, there's a couple of things. The rate of the reaction is increased with increased temperature. Remember the match. And also, the rate of the reaction is increased with increased concentration of ingredients. Remember 20 percent oxygen, 100 percent oxygen.

Interior and exterior factory shots

NARRATOR (NAT SOUND under):
Temperature and concentration. Is there another general way of speeding reaction rate? There is, and it is employed in most reactions in the chemical industry. It involves using substances called catalysts.

DS in lab

DON SHOWALTER (SYNC):
Here I have a white powder, sodium potassium tartrate, about 30 grams. I want to dissolve that into this warm distilled water. The water's at about 70 degrees Celsius. That's a fairly large molecule. I want to perform a chemical reaction for you where I break this big molecule down, degrade it. (cont.)

DON SHOWALTER cont:
The way I do that is by adding hydrogen peroxide, a fairly strengthy solution, 30 percent hydrogen peroxide. Now, if there is a reaction, you should be able to see carbon dioxide given off, bubbles. Let's see if it happens. I'll pour it in there. Oop. Not many bubbles. Even though I heated it, and we know that heat increases the rate of a reaction. It didn't speed it up. So what else can we try? How about a catalyst? Let's add a catalyst. I'll put it into this container just in case it does go pretty fast. Now, here's the catalyst. It's a solution of cobalt chloride. Let's add that to this reaction mixture and see what happens. Now, a catalyst will speed up a chemical reaction. And look what's happening. The carbon dioxide bubbles are being given off, but one other stipulation for a catalyst is it must be the same at the end as it was at the beginning. Look at the rate of reaction. Notice it's green, so the catalyst is actually taking part in the reaction. Look at the steam being given off here. Oh. Now, if it's a true catalyst, what should happen? It should be the same at the end as it was at the beginning. Look at the color. It's back to that original pink color. What's a catalyst? It speeds up a chemical reaction, but it must be the same at the end of the reaction as it was at the beginning. It's pink again.

Slow motion shots of wine being poured into glasses

NARRATOR (MUSIC and NAT SOUND under):
Special biological catalysts, called enzymes, are present in yeast, and that's important to the fermentation process in wine making. It's one interest of food chemists like Dr. Theodore Labuza.

INTERVIEW: Dr. Theodore Labuza, food chemist

SUPER: Theodore Labuza

DR. THEODORE LABUZA (SYNC/VO):
The production of wine from grapes is a fermentation process. In this case, we take grape juice, which contains sugars, and we add a yeast to it.

Shots of wine making

In the ancient days, they didn't add yeast because they didn't know what yeast was, but there's naturally present yeast on the grape skins itself. And under the right temperature conditions, the yeast will ferment the sugars in there, produce alcohol, and the alcohol, in fact, prevents the growth of other microbes that would spoil it. If you didn't hold it under right conditions, you would end up with something that was really God-awful, it would not be a good Cabernet Sauvignon.

MONTAGE: Food transportation shots, sheep in New Zealand, food packaging

NARRATOR (MUSIC and NAT SOUND under):
Food is shipped across America and around the world. The rates of food spoilage, the rates of reaction, are vital knowledge for our global economy. A far-off country like New Zealand, for example, is almost wholly dependent on overseas markets for its lamb and butter and cheese. How do scientists study food spoilage and preservation?

Food packaging

DR. THEODORE LABUZA (VO/SYNC):
The kinds of reactions that cause food to spoil are not very different than what chemists study in pure chemical solutions, see.

INTERVIEW: Dr. Theodore Labuza cont.

Where I always like to talk about food, it's the study of messy chemistry. And the reason I say that is that, in a food which has so many different organic compounds and inorganic compounds together, there are lots and lots of different reactions that could have caused spoilage. What we can do, however, is narrow them down to several classes. One, reactions that are enzyme catalyzed. (cont.)

DR. THEODORE LABUZA cont:
For example, when you bite into an apple, you see it start to brown. That's an enzyme reaction. There's reactions that make it go rancid. Potato chips, for example, if they sit around for a long time, the fat goes rancid.

Shots of food preparation and packaging

NARRATOR (NAT SOUND under):
Modern techniques of food preparation and refrigeration have greatly reduced spoilage. Still, the shopper might like further proof that reactions have been retarded, that food is as fresh as possible.

INTERVIEW: Dr. Theodore Labuza cont.

DR. THEODORE LABUZA (SYNC/VO):
One of the more interesting things that we're doing in our laboratory here, which is an application of chemical kinetics,

Food chemists at work in lab, food packaging and spoilage label

is the study of little devices that can be used to monitor time-temperature when a food goes through a distribution cycle. Now, why do you want to do that? (cont.)

DR. THEODORE LABUZA cont:
Well, since foods deteriorate at a faster rate when the temperature goes higher, and at a slower rate when the temperature goes lower, if you had a device that could be put on a package that would essentially integrate the time-temperature exposure and show a color change that could be related to the loss of quality of the food, then, by simply picking up a package and looking at a device that may be on the package, you could tell how much more shelf life is left, so you'd know when to consume it.

Rocket launch shots,
freeze drying foods

NARRATOR (MUSIC and NAT SOUND under):
From supermarket to space. The manned space program has been an exciting challenge for the food chemists investigating rates of reaction. Dr. Labuza.

Astronauts in space,
eating freeze-dried foods

DR. THEODORE LABUZA (VO):
Why would one want a very long shelf life for space foods? The astronauts were only up there for a matter of days to maybe several weeks. Well, in fact, the foods had to be produced maybe six to nine months ahead of time because we never knew when a rocket was gonna go off. (cont.)

DR. THEODORE LABUZA cont:
And so they had to have the foods in storage, and what we wanted to make sure was by the time the rocket went off, the food was still of good quality. And that's why we really had to study the rate at which the quality was lost and the package it in such a way that we could minimize that rate of quality loss.

SUPER: THE DRIVING FORCES

MONTAGE: Chemical reactions, fire, construction workers, food preparation and packaging

NARRATOR (MUSIC under):
To review, in any chemical reaction, substances are transformed into completely different substances. The natural direction of a chemical reaction is determined by the tendency to go in the direction of lower energy and higher entropy. In an exothermic reaction, energy is released. In an endothermic reaction, energy is absorbed. The speed of a chemical reaction is determined by the nature of the substances involved, as well as their concentration and temperature. A catalyst is a substance that increases the rate of a chemical reaction. Sometimes, as in the case of preserving food, it is necessary to slow down a chemical reaction.

RH in field

ROALD HOFFMANN (SYNC):
You know, when I see that reaction that Don Showalter ran in the laboratory, when he mixed hydrogen peroxide with a solution of sodium potassium tartrate and at first nothing happened, and then he added a catalyst and there were color changes and bubbling, when I see that, a terrible urge overcomes me. I want to know what happens in there. I'm not satisfied with seeing the colors. I want to see what the molecules are doing. How can I do that? How can I find out something about those tiny things? Well, those colors can be looked at with a spectrometer. Those messages from within can be decoded. Oh, they happen quickly, those color changes, but I can try to move quickly, I can try to fight nature and slow down the reaction by cooling it. I can build a faster spectrometer. Slowly, laboriously, we can build up a picture of what happens in a chemical reaction, whether it's Don's experiment or in the leaves of that tree. The explanation must lie at the molecular level. This is what we'll see in the next program.

Credits, Closing Montage, Closing Music

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